

NASA Standard for Models & Simulations

FEMCI Workshop

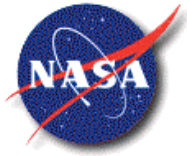
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October 26, 2006



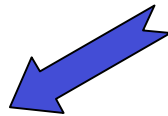
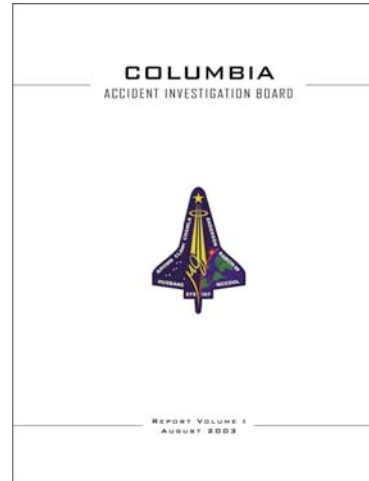
Objectives

- Explain the genesis and scope for the NASA Standard for Models and Simulations (*aka* M&S Standard)
- Describe the goals and top-level decisions of the M&S Standard
- Survey representative requirements

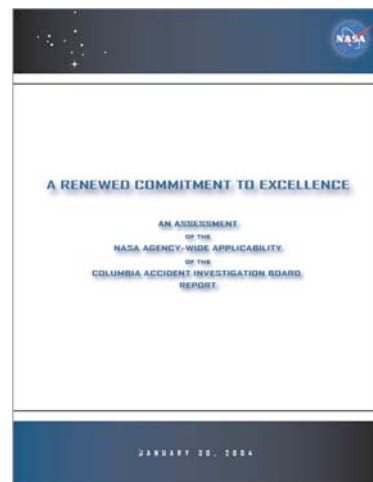
Response to Columbia Accident

Columbia Accident Investigation Board (CAIB)

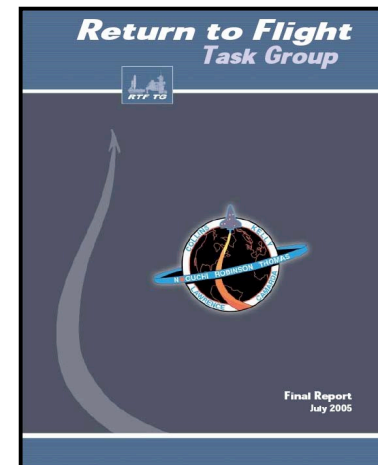
February 1, 2003

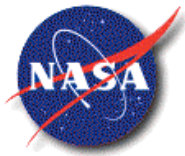


**A Renewed Commitment to Excellence
(Diaz Report)**



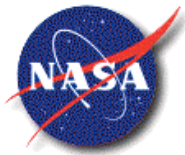
**Return-to-Flight Task Group
(Stafford-Covey Report)**





Diaz Action #4 Requirements

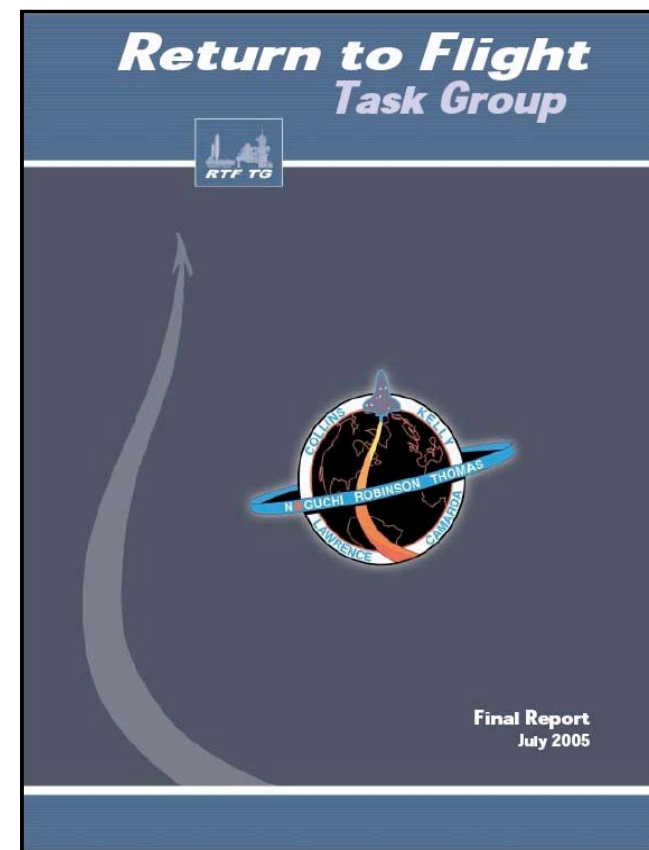
- **Develop a standard for the development, documentation, and operation of models and simulations**
 - Identify **best practices** to ensure that knowledge of operations is captured in the **user interfaces** (e.g. users are not able to enter parameters that are out of bounds)
 - Develop process for tool **verification and validation, certification**, reverification, revalidation, and recertification based on **operational data and trending**
 - Develop standard for **documentation, configuration management, and quality assurance**
 - Identify any **training or certification requirements** to ensure proper operational capabilities
 - Provide a **plan for tool management, maintenance, and obsolescence** consistent with modeling/ simulation environments and the aging or changing of the modeled platform or system
 - Develop a process for **user feedback when results appear unrealistic** or defy explanation

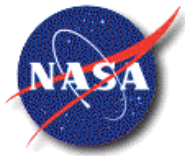


Stafford-Covey Annex A2 Remarks

(http://returntoflight.org/reports/final_report.html)

- “... during the return-to-flight effort, there has been an enormous expenditure of time and resources - amounting to tens of millions of dollars - without the discipline of a formal **development plan**, clear objectives, **explicit plans for verification and validation**, thorough **outside review**, documented ICDs between models, or a good understanding of the limitations of analytical systems employing **multiple, linked deterministic models**. Validation and verification planning has been left to the end of the process rather than the beginning. ... Analytical models have essentially driven the return-to-flight effort; however, industry and academic **standards and methods for developing, verifying, and validating the models have not been used**. In addition, no sensitivity analyses had been conducted and no empirical data from flight history had been incorporated in the models or their validation”





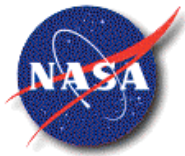
Participants in Standard Development

- **Development Team [NASA LaRC] (1.5 year, 3.0 FTE)**
 - Developed initial 3 versions of Standard
 - Provided recommendations to Topic Working Group on changes to Version 3
- **Topic Working Group [all Centers but DFRC] (0.5 year, 0.5 FTE)**
 - Provided comments on Version 2
 - Modified Version 3 and adopted Version 4 (Interim Standard)
 - Decides disposition of comments on Version 4
- **Technical Standards Working Group**
 - Oversees formal input from all NASA centers for permanent standard
- **Engineering Management Board**
 - Approves standard
- **NASA Chief Engineer [Chris Scolese]**
 - Issues standard



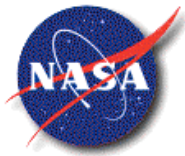
Goals of the M&S Standard

- The **primary goal** is to ensure that the credibility of the results from models and simulations is properly conveyed to those making decisions that may affect human safety or project-defined mission success criteria
- The **secondary goal** is to assure that the credibility of the results from models and simulations meets the project requirements
- **Mission Success Criteria:** Standards against which the program or project will be deemed a success. Mission success criteria may be both qualitative and quantitative, and may cover mission cost, schedule, and performance results as well as actual mission outcomes (*NPR 7120.5C*)
- **Critical Decision:** decision that may affect human safety or project-defined mission success criteria



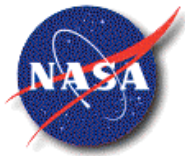
Additional Considerations

- The M&S Standard should apply to large-scale, medium-scale and small-scale projects, e.g.,
 - Constellation
 - Mars Science Laboratory
 - Global Tropospheric Aerosols
- Requirements that will commonly be waived should not be included
- We need as an end-product concise documents that M&S practitioners and project managers
 - are willing to read
 - can understand
 - will accept
- This Standard needs eventually to be supplemented by Guidebooks (Recommended Practices) that enable the above



Scope of M&S Standard

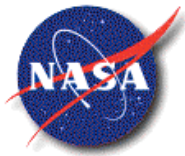
- The scope of the M&S Standard is a NASA HQ policy issue
- **Flight and ground control software are out of scope**
- The following charts provide further clarification



In-Scope M&S Uses

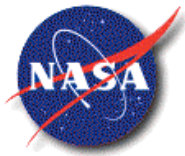
(provided the M&S affects critical decisions)

- **Operations**
 - analysis of the status, anomalies, and corrective actions during mission operations and mission simulations
- **Manufacturing, Assembly, Test & Evaluation**
 - manufacturing/assembly/evaluation/verification of hardware & software artifacts; this includes the stimulation environment of control systems and displays, e.g., the atmospheric properties and aerodynamic database for a flight simulator
- **Design & Analysis**
 - evaluation and exploration of solution spaces for current and future systems and subsystems
 - this includes design and analysis performed to support acquisition decisions and mission planning
- **Natural Phenomena Prediction**
 - whenever the simulation of natural phenomena is a NASA responsibility, e.g., Near Earth Objects



Out-of-Scope M&S Uses

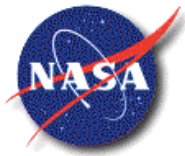
- **Technology Investment**
 - identification and evaluation of candidate advanced technologies for future missions and systems
 - (M&S of advanced technologies under development for a specific mission is in scope)
- **Scientific Data Analysis**
 - processing of scientific data collected by instruments
 - (engineering data, e.g., for IVHM , is in scope)
- **Scientific Understanding**
 - simulation of natural phenomena used for advancement of scientific knowledge
- **Training and/or Education**
 - producing learning in a user or participant
- **M&S Research**
 - conception, development and evaluation of knowledge and practices for models and simulations



Important Qualifier

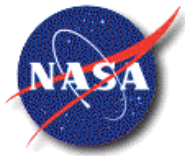
From the Interim M&S Standard:

“If existing models and simulations that were not developed under terms of this standard are subsequently applied to ... uses that support critical decisions, then all the requirements of this standard must be met.”



Comments on Current NASA Guidance

- Current NASA guidance is strongly oriented towards control systems and displays
- NASA has existing or imminent NPD's, NPR's and Standards that cover many of the generic software engineering aspects of the Diaz #4 requirements, especially
 - Quality Assurance and
 - Configuration Management
- The unique, critical aspects of Models and Simulations (M&S) are not addressed, especially
 - development of models
 - validation against experimental or flight data
 - uncertainty quantification
 - operations and maintenance of M&S



Observations on Other Agency Guidance

- Neither Sandia, nor the Dept. of Energy in general, has an M&S standard
- The Nuclear Regulatory Commission standards (like NASA's) are strongly oriented towards control systems & displays, and the unique, critical aspects of models and simulations are not addressed
- The Dept. of Defense has numerous directives, instructions, guidebooks, etc., but it has no M&S Standard with hard requirements
- The following documents from non-NASA sources address some of the gaps in existing NASA guidance
 - *VV&A Recommended Practices Guide* from DoD
 - *AIAA Guide for Verification and Validation of Computational Fluid Dynamics Simulations*
 - *ASME Guide for Verification and Validation in Computational Solid Mechanics* (in press)
 - Various Sandia National Laboratories documents
- Existing guidance is overwhelmingly focused on the development of M&S (especially V&V)—some guidance is available on operations and virtually none on maintenance of M&S



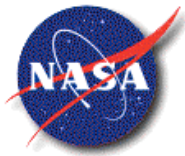
Outline of M&S Standard

1. Scope
 2. Applicable Documents
 3. Acronyms and Definitions
 4. Requirements
 - 4.1 Programmatic Requirements
 - 4.2 Models
 - 4.3 Simulations and Analyses
 - 4.4 Verification, Validation and Uncertainty Quantification
 - 4.5 Development and Use of Recommended Practices
 - 4.6 Training
 - 4.7 Assessing the Credibility of Models and Simulations
 - 4.8 Reporting Results to Decision Makers
 5. Guidance
- Appendix A: Multidimensional Credibility Scales
- Appendix B: Requirements Traceability Matrix

4.2 Models

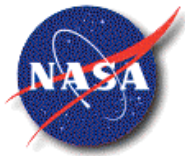
The responsible party:

- Req. 4.2.1 – Shall document the assumptions and abstractions underlying the model, including their rationales
- Req. 4.2.2 – Shall document the basic structure and mathematics of the model (e.g., physics included, equations solved, behaviors modeled)
- Req. 4.2.3 – Shall document data sets, facilities, and any supporting software used in model development and input preparation
- Req. 4.2.4 – Shall provide documentation of the limits of operation of computational models to those responsible for using them in simulations, analyses, and reporting to decision makers.
- Req. 4.2.5 – Shall document the uncertainty quantification and uncertainty in any data used to develop the model or incorporated into the model
- Req. 4.2.6 – Shall provide guidance on proper use of the model
- Req. 4.2.7 – Shall document any parameter calibrations and the domain of calibration
- Req. 4.2.8 – Shall document updates of the model (e.g., solution adjustment, change of parameters, calibration and test cases) and assign unique version number, description, and the justification for the update
- Req. 4.2.9 – Shall justify and document obsolescence and obsolescence date of the model
- Req. 4.2.10 – Shall provide a feedback mechanism for users to report unusual results, etc. to model developers or maintainers



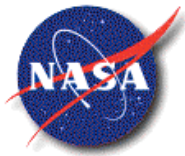
4.4 Verification and Validation

- For verification, the responsible party:
 - Req. 4.4.1 – Shall document the verification status of the computational model
 - Req. 4.4.2 – Shall document the verification techniques used
 - Req. 4.4.3 – Shall document any numerical error estimates of the results pertinent to the intended use, for example, ...
 - Req. 4.4.4 – Shall document the domain of verification (e.g., the conditions under which verification was conducted).
- For validation, the responsible party:
 - Req. 4.4.5 – Shall document the model validation studies that have been conducted for the intended use of the M&S, including the experimental design, analysis, results of model validation, validation metrics and data sets used for model validation, along with all associated uncertainties
 - Req. 4.4.6 – Shall document the validation techniques used



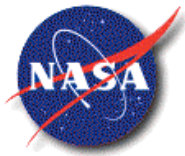
4.4 Uncertainty Quantification

- For uncertainty quantification, the responsible party:
 - Req. 4.4.7 – Shall document any processes used to quantify uncertainty, including
 - a. the M&S results,
 - b. the experimental data,
 - c. the input data,
 - d. the propagation of uncertainties.
 - Req. 4.4.8 – Shall document the quantified uncertainties, both physical and numerical, including
 - a. the M&S results,
 - b. the experimental data,
 - c. the input data,
 - d. the propagated uncertainties.



4.8 Reporting Results to Decision Makers

- Req. 4.8.1 – Reports to decision makers shall include the achieved levels for all acceptance criteria defined in Req. 4.1.5
- Req. 4.8.2 – Reports to decision makers of results generated by simulations for which any waivers were granted shall clearly state the waivers
- Req. 4.8.3 – Reports to decision makers of results shall include an estimate of the uncertainty and a description of the process used to obtain the uncertainty estimate. The uncertainty estimate shall include either
 - a. A quantitative estimate of the uncertainty in the test data and derived results, or
 - b. A qualitative estimate of the uncertainty in the test data and derived results if a quantitative estimate is not available, or
 - c. A clear statement that no quantitative or qualitative estimate is available
- Req. 4.8.4 – Reports to decision makers containing results generated by simulations that were conducted outside the limits of operation of one or more models shall contain a prominent statement to this effect, along with at least a qualitative estimate of the impact of this usage
- Req. 4.8.5 – Reports to decision makers shall include a presentation of the level of credibility for the M&S results, using the process defined in Section 4.7



Path to Permanent Standard

- Complete Interim Standard
- Centers conduct pilot studies of Interim Standard
- Topic Working Group (TWG) conducts several workshops to converge on a common scale
- SWG and M&S TWG agree on applicable requirements of NPR 7150
- TWG assesses results of pilot studies of Interim Standard
- NASA Technical Standards Working Group circulates Interim Standard for formal comments from centers and programs/projects
- TWG dispositions all comments & revises Standard
- Engineering Management Board approves revised Standard